

An Hybrid Simulation model to support decision making in a manufacturing plant

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Abstract: - The objective of the following paper is to determine a quantitative approach is generic enough and able to reproduce the logical steps for the construction of tools for decision support systems. The heart of the problem is the use of simulation techniques based on the concepts of System Dynamics. A further innovation is logged in the System Dynamics is to demonstrate how an efficient technique used in decision support systems, not only strategic, but also tactics. The paper will consist of five sections. First we will describe the main characteristics of the DSS and their role in decision-making. In the second section we focus will shift on the simulation, in particular, we highlight the differences between the various techniques and its role within the DSS . In the last few three sections it will be a case study, which will be exposed, as we were able to solve a problem using the System Dynamics. In particular, there will be an in-depth analysis of the problem. In the fourth will turn to an analysis of data and the description of the simulation model. Finally, in the fifth and final section, we discuss how the simulation was carried out and the results thereof, the latter will be analyzed and be put forward ideas for resolving the problem, the simulation will be performed again and will report the results of various scenarios.

Key-Words: - System Dynamics Simulation, Modeling and Simulation, Decision Support System.

1 Introduction

A Decision Support System (DDS) is composed by a series of methodologies adapted to support the decision-making process. From the quite explicative name, it can be also deduced what are the basic elements of DDS:

- *Decision:* indicates the focus to decision-making activities and to executive problems;
- *Support:* indicates that information technologies are helpful in making decisions, but don't replace the decision-maker, who remains the leading actor; the latter must be able to analyze the data in real time from different points of view and at different levels of aggregation, having quantitative data available;

- *System*: highlights that these tools seeks the integration between users, machines and analysis methods.

Usually, DDS's are identified by software to which is required ability to consolidate information, to provide reports or forecasts, to allow simulations, in a flexible and simple way.

Very often it is not just the intuition or the ability of the decision maker what most determines the development or the survival of a company, but the speed at which a decision is made and thereby the reduction of the problem-action gap. The answer ready in a short time allows a continuous adaptation to both internal and external changing environment, even if this leads to a suboptimal solution and, therefore, can be improved with more data and further analysis. This is why the main goal of a DSS is to allow us to extract, in a timely and flexible manner, by a large amount of data, information that serves to support and enhance the decision-making process in terms of effectiveness.

Usually, in business, DDS's are used to support the decision-maker in making strategic and tactical decisions. These decisions are also defined, respectively, unstructured and semi-structured. An unstructured decision has not a preset decision-making procedure and, for this reason, it is called non-programmable. The absence of precise rules can be traced back to the fact that it is often difficult to understand how these decisions are made, or they are too variable to establish a general algorithm. Moreover, data or information required are not defined a priori and they need to be analyzed according to different models.

Another feature is the frequency, lower than that with which structured decisions are made.

A decision is structured if it is possible to specify for it a series of deterministic and preset rules (an algorithm) in order to reach a solution; such decisions are called programmable.

Finally, some decisions have a mixed structure, being formed by both programmable and non-programmable elements and they are defined semi-structured.

A decision-making process is a sequence of elementary activities that occur when an individual or an organization makes a decision. Every activity of choice produces results that can generate interactions.

For the majority of scholars, decision-making process can be represented with the model proposed by Simon in the 60s in his "The New Science of Management Decision" that is still considered satisfactory. The latter divides the process into three

main phases, from each of which it is possible to return to the previous. They consist of:

- *Intelligence*: this is the phase in which is gathered information from both the internal and the external environment to identify and delineate a problem to be faced;
- *Design*: this phase consists in understanding the problem, generating possible solutions and analyzing them. It is at this stage that intervene the skills and the experience of the decision-maker, as well as his creativity especially in generating alternatives;
- *Choice*: in this phase, the options formulated in the previous step are evaluated and then selected. Are defined, for this purpose, some parameters and indicators, that allow us to compare action plans and to make predictions about what will be the consequences of choices.

In the present work, we tried to contribute to the development of new quantitative tools that provide a systemic vision for the implementation of decisions.

2 Problem Formulation

System modeling is a very useful method and can be considered the core of the decision support systems. In order to be able to proceed properly to have a simulation model useful and running, it is appropriate to follow a procedure that can be schematized in the following seven steps:

1. problem formulation and choice of target;
2. data collection and processing;
3. construction of a logical-mathematical-statistical model;
4. preparation of a computer program;
5. validation of the model;
6. planning and execution of simulation experiments;
7. analysis and presentation of results.

The first two steps are used to understand inside and out the problem and lay the foundations for the construction of a working model. Constructing a mathematical model involves identifying the components of the system under consideration and the functional relationships that links these components together. Thereafter, this information has to be translated into a computer program. In order to create a model that can be classified as a DDS, validation step is essential. In fact, this step allow us to understand whether the constructed model is robust and, than, if it is possible to detect the performance of the system under conditions different from those existing. In other words, a robust model enable the transition from real word to

virtual. The last steps provide the determination of the simulation plans and the analysis of the results, since this is not an optimization technique.

The simulation techniques and the resulting modeling approaches that can be used are three: Discrete Event Simulation (DES), Agent Based (AB) and System Dynamics (SD).

Using the DES, the system evolves at time intervals (that may also not be equal) alternated with pauses of inactivity; the times when events occur, that are the cause of system evolution, are well defined, while between one event and another system status does not change.

With the AB, system is modeled as a group of independent subjects, able to implement decision-making processes, called agents. Each agent individually evaluates its situation and makes decisions based on a set of rules.

In SD, variables status changes continuously as a function of time. The underlying logic of the System Dynamics allows the construction of scenarios, understood as a tool to support learning and the effective formulation of decisions. In particular, when operating in conditions of rapid change, when the environmental discontinuities make useless or misleading the predictions based on extrapolation of historical data, this logic is an efficient tool in the planning phase. The main feature of the systems studied by the System Dynamics logics is that the cause-effect relationships are non-linear, but have typical mechanisms of feedback, so we are faced with feedback loops in which variables influence each other.

A further feature that must have a DSS quantitative tool is flexibility and speed in giving results. The model must enable the assessment of different scenarios using assumptions.

A further objective of the present work is to model a system with constructs that are completely general and can be used to represent any type of system.

3 Related works

Until a few years ago, it was thought that the greatest benefits from the use of DSS were got for those problems in which the parameters and information to be considered were numerous hard to control. It is for this reason that were planned DSS's to support semi-structured or unstructured activities. Newer conceptions have instead shown that also decisions of a more limited extent exhibit non-structurability characteristics.

Referring to the simulation techniques, it can be said that DES models better reflect systems in which entities are processed linearly, allowing to simulate

perfectly the concept of competition, that is, activities that can be carried out simultaneously. It is for this reason that DES logic is used mainly for modeling processes. For example, Charles Lakos has used Petri Nets (PN) to model hierarchical diagrams; in 2002, A. Anglani, A. Grieco, M. Pacella and T. Tolio developed a flexible simulation model for manufacturing systems; in 2009, A. Vaghefi and Vahid Sarhangian built a model for optimizing the control plans of a manufacturing system; in 2012, Seyed Hessameddin Zegordi and Hoda Davarzani realized a model for analyzing breaks in the Supply Chains using Petri Nets.

What is clear from these articles is, on the one hand, that DES is used when one is interested in a high computational precision and it is possible to follow the path of each entity, on the other hand that they are highly flexible for use in different contexts.

SD, instead, lends itself to the acquisition of all the aspects and of all the variables, not only those closely related to the process within a closed system, but also to those which, in some way, affect the decisions (this is thanks to the clarification of feedback loops). It is for this reason that the SD logic is used primarily for modeling systems and not processes. For example, Kamran Shahanaghi and Seyed Ahmad Yazdian analyzed the effects of the implementation of Total Productive Maintenance in manufacturing; in 2011, Roberto Poles developed a model for inventory and production systems in order to assess the strategic improvements in manufacturing; in 2012, C. Ma, G.Y. Zhang, X.C. Zhang, B. Zhou, T.Y. Mao used this approach to model the use and protection of a Chinese coastal city; Songtao Zhang, Xiaowei Zhao, Yanting Hou developed a model based on closed-loop Supply Chains; whereas in 2013, Patroklos Georgiadis and Efstratios Athanasiou developed a model for the long-term flexibility for the capacity plans in the Supply Chains in manufacturing.

From this, it appears that SD is used when systemic precision is preferred to computational, otherwise when we are interested in information resulting from the iterations of the elements belonging to a system, more than in information resulting from the paths of the individual entities.

Another line of research concern the use of these two techniques for the creation of the so-called hybrid models, that are models that simulate the behavior of the processes with DES or AB logics and the iterations between the variables by models created through SD logics. For example, from 2010 to 2013, several authors tested this approach, creating a DES/SD model in the health sector, whereas, still in 2012, C. Laroque, J. Himmelspach,

R. Pasupathy, O. Rose, and A.M. Uhrmacher created an AB/SD hybrid model on social and health care for age-related macular degeneration. What can be realized from these articles is that hybrid models are used when we are interested in obtaining macroscopic (by DES and AB) and microscopic (by SD) information and, in practice, the results of a model affects those of the other one, creating loops. Obviously, the resources used for a detailed work such this are considerable and not always available, both in terms of time and in terms of cost.

4 Case Study

The modeling technique above mentioned, was tested for solving a problem in manufacturing. The company treated has a problem as regards the department of repair and testing. In this department products come from three flows, the first deriving from the programmed production, the second from products that must be reworked and the third deriving from the products that customers send for assistance.

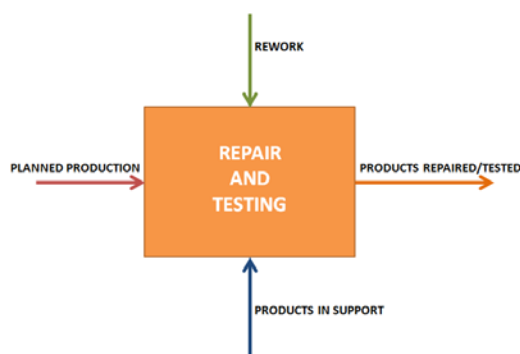


Fig. 1: Testing and Reparation Model

While for the products of the first two flows there isn't a deadline in delivery, delays in delivery of products in assistance involves the payment of exorbitant penalties.

When a product comes by the customer, before this can be processed, it must wait for the completion of the repair of the piece already in the works, then it takes priority over other products in the queue. In this way, the Lead Time of the product that comes from the outside becomes longer, with a consequent delay.

To solve this problem it followed the steps for building a DSS and, then, a study focused on the degree of saturation of human resources.

First of all it was implemented a phase of analysis for the collection of processing times of each department and in particular of the critical department. This analysis detected an excessive

workload to the resources of the department in question and an under saturation of resources in other departments. After this phase we carried out Fitting tests. In this way, the data collected was left out and we have used the theoretical distribution curves.

These sources of randomness are used to represent the diversity of these characteristics, as they are found in reality. However, they have a large effect on the results of the simulation, and different simulation runs can therefore produce very different results, due to a different sequence of random numbers that happen to be drawn for the mentioned processes.

This stochasticity in the results of simulation runs has been widely recognized, but unfortunately they are sometimes ignored when such simulation models are applied. The usual way to deal with the random variation of the simulation results, given the same input data, is to replicate the simulation runs a number of times, and take the average of the measures of interest. These measures of interest are usually called Measures of Effectiveness (MOEs).

When these MOEs have been defined, it is important that the simulated quantities can be compared to the field data. In order to do so, a good estimate of the mean value of these quantities across the simulation runs (which produce varying results) needs to be obtained. It was necessary to identify the number of run useful to get results with a minimum error.

This number was identified with the following formula:

$$N(m) = \left\lceil \frac{S(m)t_{m-1,1-\alpha/2}}{\bar{X}(m)\varepsilon} \right\rceil^2 \tag{1.1}$$

Wherein:

$N(m)$ is the number of replications required, given m replications;

$\bar{X}(m)$ is the estimate of the real mean μ from m simulation runs (samples);

$S(m)$ is the estimate estimate of the real standard deviation σ from m simulation runs;

α is a level of significance;

ε is Allowable percentage error of the estimate $\bar{X}(m)$;

$$\varepsilon = | \bar{X}(m) - \mu | / | \mu |.$$

$t_{m-1, 1-\alpha/2}$ is a critical value of the two-tailed t -distribution at a level α of significance, given $m-1$ degrees of freedom.

Using this formula the required number of replications $N(m)$ can be calculated, based on an initial number of replications to obtain a good point estimate $\bar{X}(n)$ of μ , the real mean of the simulated quantity.

The number N of runs to obtain an acceptable error (around 0,5) with a probability of 99% is approximately equal to 11000, since the sample standard deviation was calculated after a hundred observations.

The considered simulation time is a year, while the time step is one minute.

As regards the validation, they were considered some values at specific points in the system. The information in our possession are:

- In the intermediate storage they are stored around 200-300 members.
- The number of finished products per year varies between 30 and 40.

After performing the simulation, it was found that on average in the intermediate storage at the end of a year of simulation are stored around 250 components, whereas the finished products are around 37.

The simulation confirmed the problems identified during the analysis phase. In fact the degree of saturation of resources of the department of testing are saturated to 95% those of the repair department to 100% (Fig. 7), which inevitably translates into reality with a supersaturation and delays. For the production department, also, it was found a degree of saturation of 66% since on average the number of resources used is 32 than 44 available. All this implies an average delay in delivery times of 10 days.

To resolve this problem, we proposed three possible solutions reallocating 10 resources of the production department. The first is that five resources are allocated in the testing department and 5 in the repair department. This solution implies a considerable reduction of lead times which comply with the terms with a degree of saturation of the resources of the department of testing equal to 90%, of the production department equal to 75% and the department of repair equal to 71% (Fig. 8). This solution is efficient but not effective because, considering the resources of the department of repair, resources that were already present are saturated to 90% whereas those added to 52%.

The second proposal was made to search for this efficiency. The reallocation was made by positioning 5 resources in the testing department and 5 for the creation of a team of joker resources.

The latter split their time working between the department of repair and the production department.

In this way, the degree of saturation of resources of the department of testing and the production does not change, instead that of resources of the department of repair is 87% whereas the joker resources are saturated to 65%. The degree of saturation of the resources of the department of repair and joker together is 76%.

The third proposal is structured the same way as the second, the difference is the abolition of priority.

In this way, the degree of saturation of resources of the department of testing and the production does not change, instead that of resources of the department of repair is 88% whereas the joker resources are saturated to 71% (Fig. 2). The degree of saturation of the resources of the department of repair and joker together is 79%.

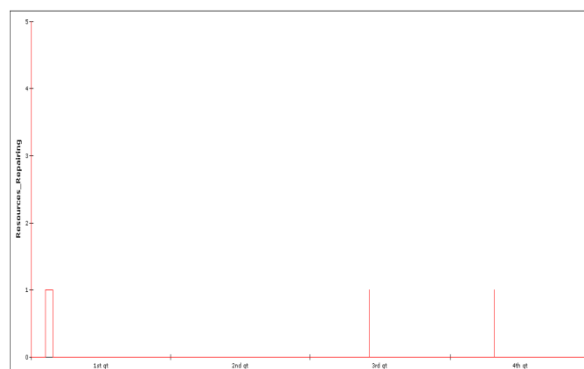


Fig. 2: Free resources in the reparation cell (current scenario).

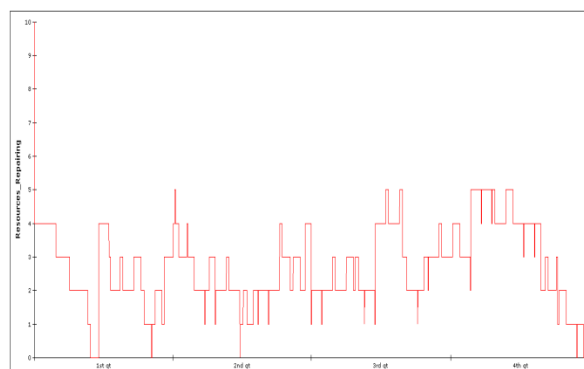


Fig. 3: Free resources in the reparation cell (first scenario).

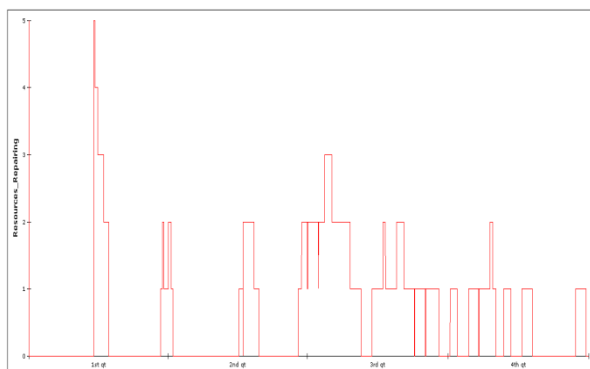


Fig. 4: Free resources in the reparation cell (third scenario).

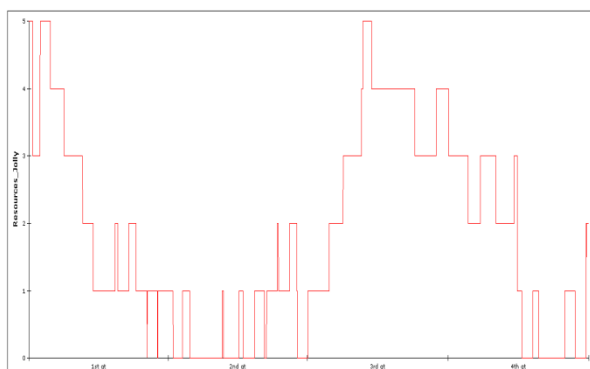


Fig. 5: Jolly resources (third scenario).

Following is a table that summarizes the results of the simulation for different scenarios.

DEPARTEMENT	SATURATION GRADE			
	CURRENT SCENARIO	SCENARIO I	SCENARIO II	SCENARIO III
PRODUCTION	66%	75%	75%	75%
TESTING	> 95%	≈ 90%	≈ 90%	≈ 90%
REP 10 RES RES+ JOLLY	/	71%	76%	79%
REP (FIRST 5)	100%	90%	87%	88%
REP (LAST 5) RESOUR JOLLY	/	52%	65%	71%
LEADTIME	70 gg	55 gg	56 gg	55 gg

Table 1: Results Table

5 The Model

This research, based on other work mentioned previously, has led to the definition of a new type of model, and thus to a new possible definition of

"hybridization". What is theoretically possible to do is take the advantages of the SD and DES techniques to create a single model in a single simulation environment, eliminating feedback loops that there are necessarily when creating hybrid models integrating two models built with the two techniques. From the mathematical point of view, with the technique DES is possible to create models where interactions between the variables can be represented by a linear function of the type:

$$f(x_i)=\alpha_1x_1+\alpha_2x_2+\dots+\alpha_nx_n \quad (1.2)$$

with $i=1\dots n$.

The SD, however, manages to reproduce models with non-linear equations of the type:

$$g(f(x_i))=f(x_i) \quad (1.3)$$

with $i=1\dots n$.

With this new type of model has tried to model systems characterized by linear equations of functions not known, namely:

$$g(f(x_i))=\alpha_1f(x_1)+\alpha_2f(x_2)+\dots+\alpha_nf(x_n) \quad (1.4)$$

with $i=1\dots n$.

The model is generally divided into two parts, the first call that simulates the physical flow paths of the entity entering into the system, the other is made up of many small general constructs that simulate operations complementary to the Flow Body. The first part is a scheme that is built specifically for each system and the operation of which is similar to timed Petri nets. Practically, in order to understand, it is as if they had been put the RP inside the SD, or has tried to simulate a system of discrete variables in a continuous manner. As a given number of tokens present in previous posts, the trigger transitions in the RP, so the occurrence of a given event activates flows in SD. Of course, events that need to occur for this to happen so that everything is decided on the basis of iterations between the variables and functions are translated with the inside of the cash flow. This, compared to DES, leaving greater room for maneuver. Since the functions are ad hoc, it is possible to simulate unrestricted whatever you want. This first phase is for the most cases customized.

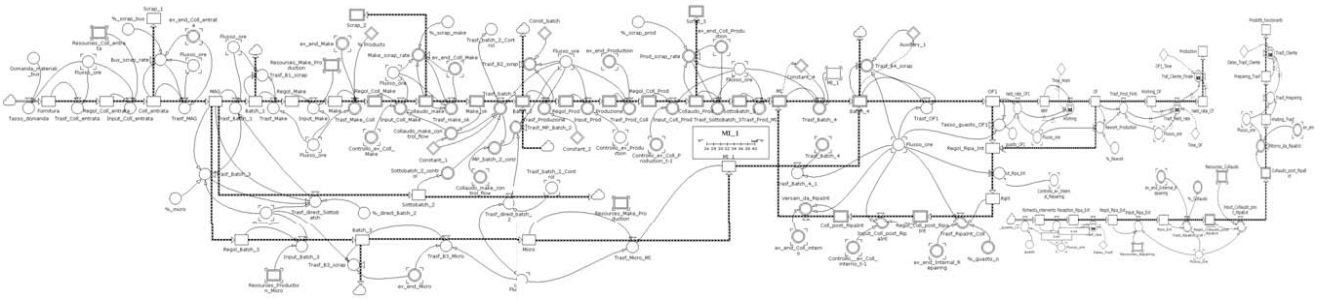


Fig. 6: Physical Flow

A trigger condition that affects all flows is that an entity is present in the layer that came before it, this is because you can not afford to variables of level of negative values, for which "freezes" the flow output when all 'interior of the previous level, there is no entity. The second part of the pattern is formed by generic constructs that can be used for modeling of any type of system, with a considerable saving of time both in the modeling phase itself is in giving an answer to the problems that a company faces. The first construct is called Chain of Events and simulates the employment of resources.

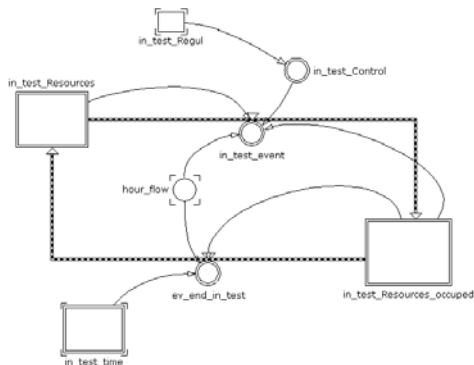


Fig. 7: Event Chain resources for incoming testing.

That of Fig 7 is a basic construct. The level *in_test_Resources* is a vector formed from a column and from a number of rows equal to the number of human resources devoted to testing operations in the entry, and is initialized with all 1. When an entity arrives from work, the variable *in_test_Regul*, which allows the connection between Event Chain and physical flow, becomes equal to 1 and all the elements of the vector *in_test_Control*, which has the same dimensions of the variable *in_test_Resources*, become equal to one. So is activated variable flow *in_test_event* inside which is written the following function:

```
FOR(i=buy|IF(ARRSUM(in_test_Control)>0 AND
SCANEQ(in_test_Resources;1)*in_test_Control[i]>0
AND
SCANEQ(in_test_Resources;1)*in_test_Control[i]=i
```

$$\text{AND in_test_Resources_occupied}[i]=0 \text{ AND} \\ \text{hour_flow}=1;1)) \tag{1.5}$$

The first condition guarantees that there is an entity to be processed, the second and the third condition allows it to occupy a single resource to a single entity ensuring its traceability in the model, ie it is always possible to know if the resource is free or occupied since his condition can be read on the same line of all air carriers, the fourth condition ensures that the resource is not already occupied. In physical flow the entity is passed from *in_test_Regul* level to the next level if there is at least a free resource, or if the sum of the elements of the vector *in_test_Resources* is greater than one. At this point, the resource will be occupied, and thus the *i*-th element of the vector *in_test_Resources_occupied* (which has been initialized with all zeros) will become equal to one. The outflow of this layer is activated by the following function:

$$\text{IF}(\text{in_test_Resources_occupied}=1 \text{ AND} \\ \text{in_test_time} \leq 0 \langle \langle \text{hr} \rangle \rangle \text{ AND hour_flow}=1;1) \tag{1.6}$$

If there is a resource busy and *in_test_time* variable is less than or equal to zero and *hour_flow* equal to 1, then the resource is freed and returns to the starting point. The Event Chain is always accompanied by another construct that simulates the passage of time taken to perform the operations, ie the time that passes from the occupation of a resource and its liberation. This construct was called *Hourglass* and is connected to Event_Chain thanks to the variable level *in_test_time*.

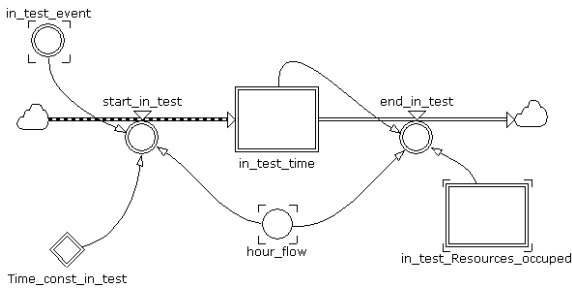


Fig. 8: Hourglass of incoming testing.

Whenever an element of the vector `in_test_event` becomes equal to one, the same row of the vector `start_in_test` becomes equal to the time constant `Time_const_in_test` that represents the time taken for testing operations. In this way it fills the variable line `in_test_time` and, when the resource is in the "occupied", the flow `end_in_test` subtracts one minute each time step line greater than zero as long as this does not clear. The evolution of these constructs gave a schema, always entirely generic, for the simulation of shared resources, or resources that are not occupied by a single type of operation but for most types. The following figure shows the simulator of shared resources from four departments. This scheme can be used even if the sharing occurs between a greater or lesser number of departments.

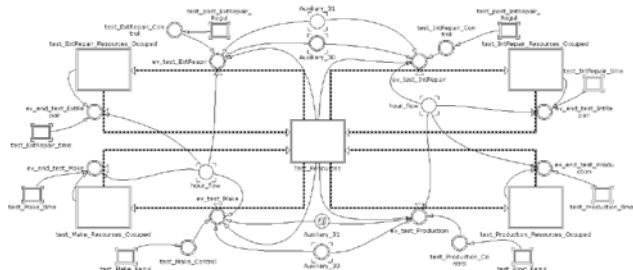


Fig. 9: Event Chain resources for testing.

The operating logic of this scheme are identical to the simplest case of Fig 6, in fact next to each Event Chain there is a Hourglass. The difficulty lies in the further management of contemporary events. In fact, if two streams are enabled at the same time, the software associated with the same resource to two different pieces bringing the level `Test_Resources` mother to take values less than zero. This problem was solved with the addition of variables and `Auxiliary_30` `Auxiliary_31` and the following structure:

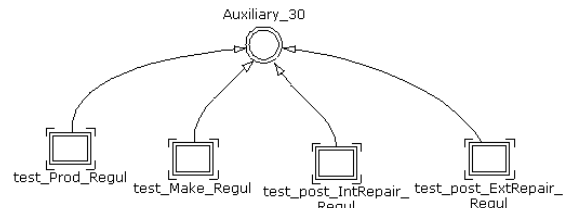


Fig. 10: Superstructure for the management of events contemporaneity.

The `Auxiliary_30` is able to check whether there is a single stream which can be enabled immediately as only one of the variables of flow shown in Fig 8 is greater than zero. If multiple streams are enabled at the same time, the `Auxiliary_31` returns a random number between zero and one, and, having fixed an interval of equal amplitude for each Event Chain, it has the same probability for each entity, arising from different flows, to be processed for before. This scheme can also be used if the products were divided into different types and may suffer different types of processing, from vectors to matrices.

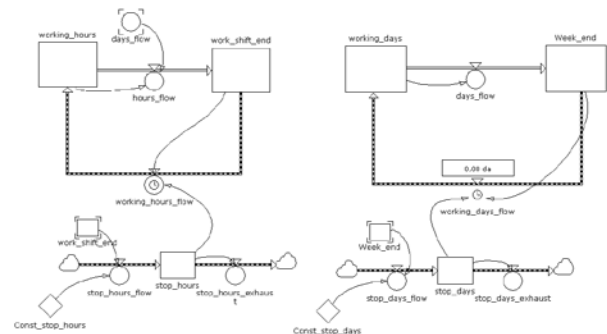


Fig. 11: Actual working time per week.

The variable `hours_flow`, which is linked to all the variables in the model, enables the flow only if it is equal to one, or if you find yourself working time. In addition to these functional constructs, they have been designed for other, more general and can therefore be used for the modeling of any system, which return the value of the performance indices in which you are interested.

5 Conclusions

The greater loss of time for the resolution of this problem concerned the data collection phase and the creation of the model. Once validated and verified that the model was robust, the simulation of various scenarios was almost immediate. Just as quickly you could simulate other types of scenarios obtaining responses almost in real time.

For this reason it can be said that we created a tool to support business decision making by using modular constructs. Another conclusion is the

possibility to reproduce, within the same working environment, logical alternatives or completely new with the ability to capture the strengths of each of them and to obtain robust models.

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